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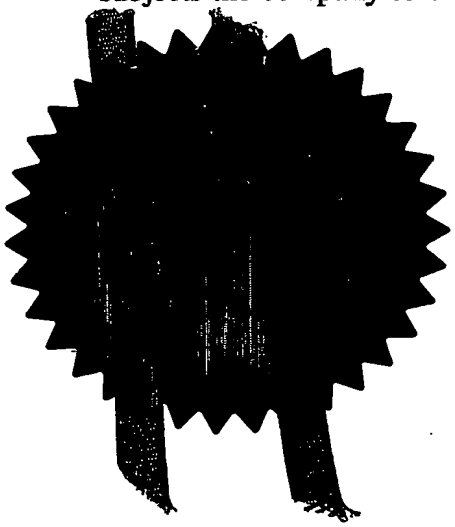

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Request for grant of a patent

(See the notes on the back of this form. You can also get an explanatory leaflet from the Patent Office to help you fill in this form)

1. Your reference NANOPAT 5

2. Patent application number *(The Patent Office will fill in this part)* 0300265.6 — 7 JAN 2003

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

Dr DEREK ANTHONY EASTHAM
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UK

Patents ADP number *(if you know it)* 8403628001

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention FOCUSSED ELECTRON AND ION BEAMS PART 2

5. Name of your agent *(if you have one)*

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Patents ADP number *(if you know it)*

6. If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number

Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*
	0213772.7	15-6-02
	0219818.2	24-8-02

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*
~~0213772.7~~	~~18/6/2002~~
~~0219818.2~~	~~27/8/2002~~

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*

a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
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Continuation sheets of this form	
Description	5 4
Claim(s)	1
Abstract	1
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11. I/~~We~~ request the grant of a patent on the basis of this application.

Signature D A Eastham Date 6 Jan. 2003

12. Name and daytime telephone number of person to contact in the United Kingdom D A EASTHAM 01925-603581

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Fig. 1

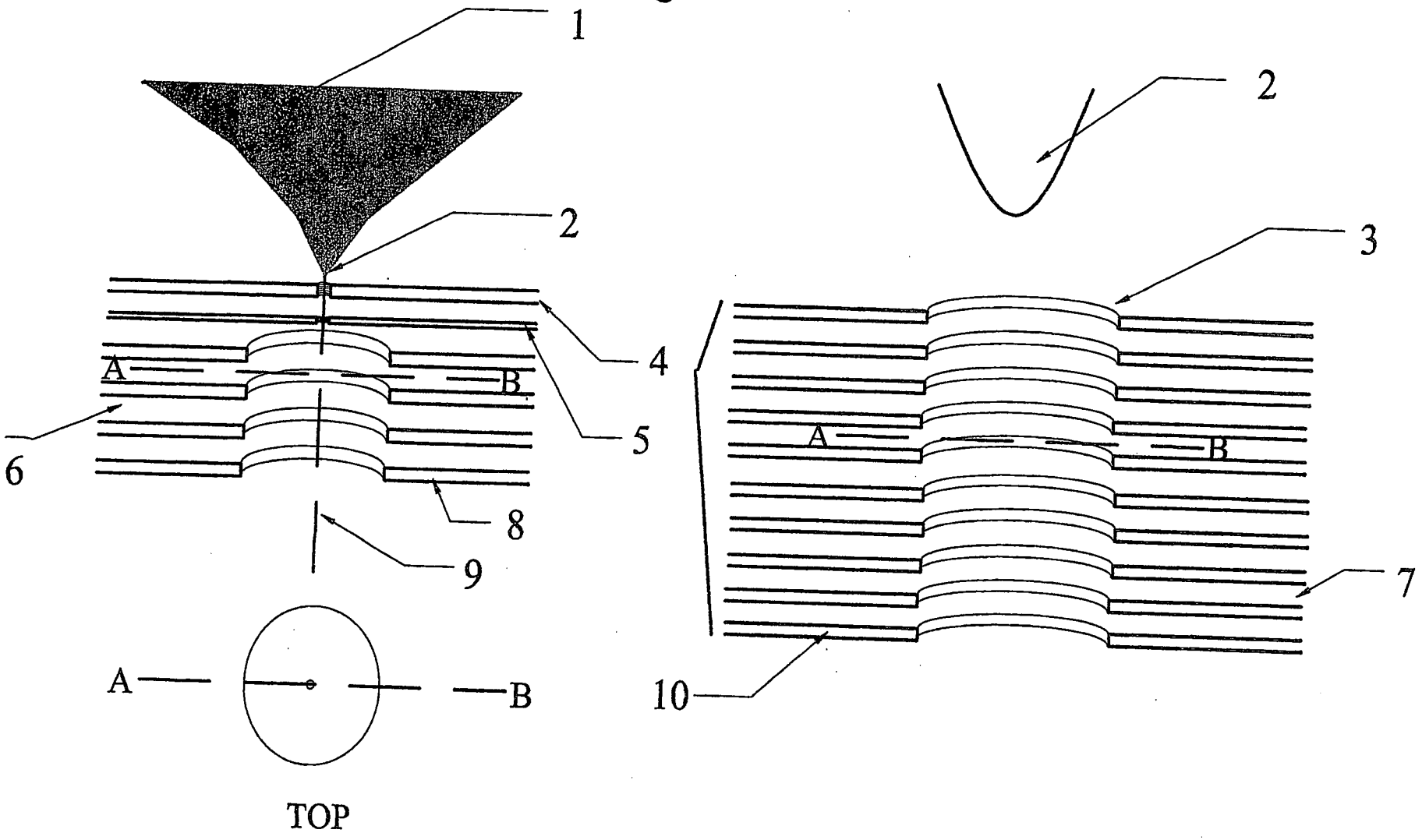
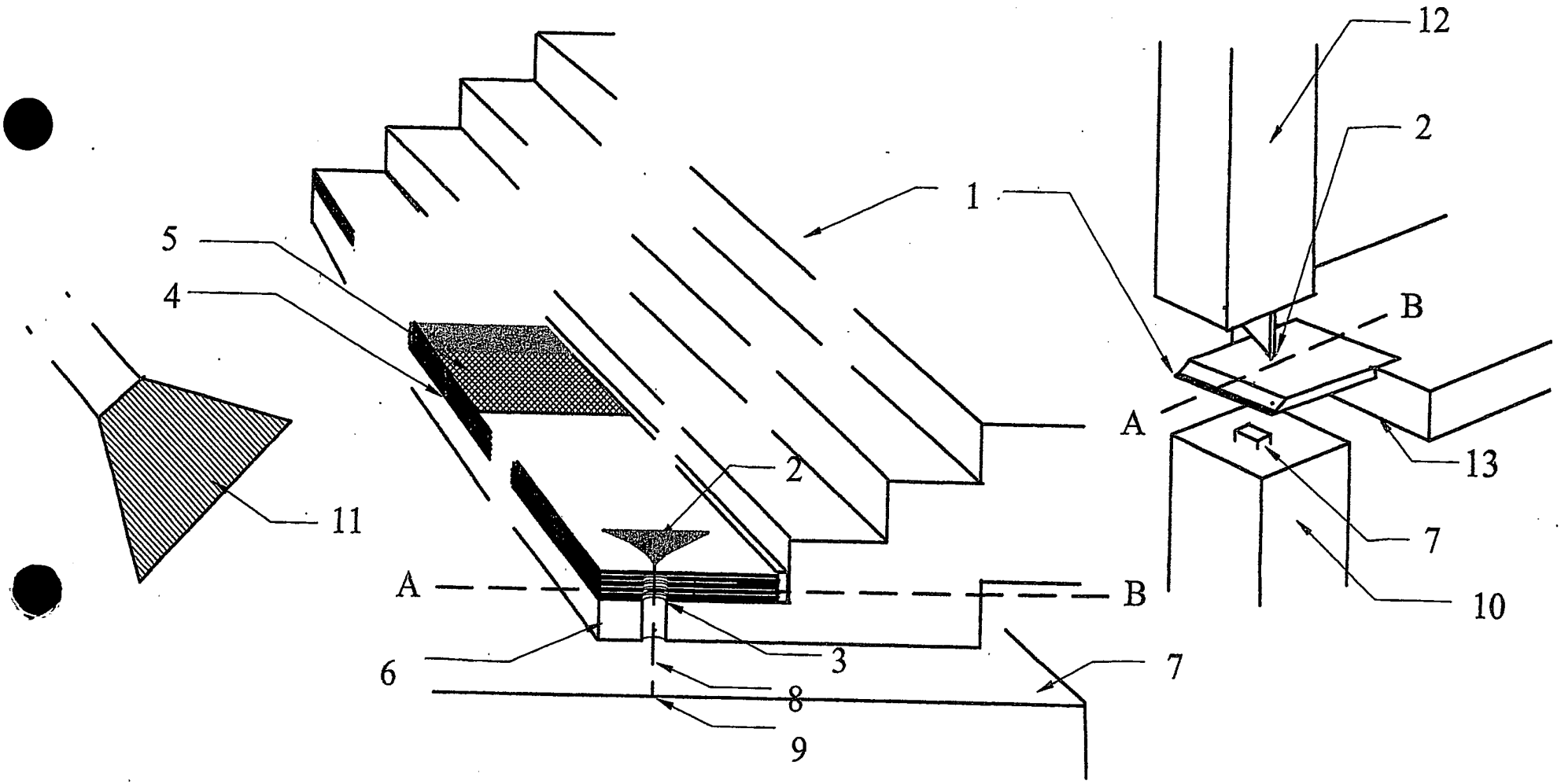


Fig. 2



Focussed Electron and Ion Beams-Part 2

In previous patent applications (numbers GB 0213772.7 and GB 0219818.2) a method of focussing electron and ion beams down to below 1nm size was described. This method has two radical improvements over existing electron microcolumns. Firstly the electrons are formed into a narrow parallel beam using an accelerating **nanocolumn**. In its simplest form the nanocolumn is merely a system of nanoscale apertures to reduce the lateral size of the beam to dimensions below 100nm. However by introducing an accelerating nanocolumn it is possible to collect almost all the electrons from the nanotip and form them into an almost parallel beam with lateral dimensions less then 50nm. In this arrangement the energy of the electrons is typically above 300eV. This beam is then focussed into a small spot using a multiple element microscale electrostatic lens.

The second radical improvement in the design is to make the focal length of this lens sufficiently small (less than about 50 μm) so that the final beam spot can have lateral dimensions below 1nm. In essence therefore the scale of this instrument is such that it is possible to contain the whole microscope in a size similar to a microchip and the term **scanning electron microscope 'on a chip'** is a succinct description for this system.

In this patent application we describe a practical system which embodies the principals of the original concept.

The system is essentially in three parts, the nanotip electron source positioned above and central to the aperture of the accelerating nanocolumn which is followed by the microscale einzel lens. Typical dimensions and voltages were given in the previous patent applications. A suitable arrangement is for the nanotip to be positioned using a vertical cantilever arrangement as used in scanning tunnelling microscopy (STM). However recent advances in lithography make it possible to incorporate this cantilever into the microscope (chip) itself. The nanocolumn consists of a multilayer of conducting (metal or silicon) thin films separated by insulating layers through which a circular hole of the required nanoscale size (typically less than 50nm) is fabricated. This is made either by lithographic techniques or by drilling using a focussed ion beam. A microscale multi-element einzel lens is positioned below the nanocolumn and concentric with it. This can be made as a separate part and can be

independently positioned with respect to the nanocolumn using standard nanopositioning systems. In a simpler form the microlens is made into the same multilayer structure as the nanocolumn and the whole forms the basic element of the microscope. Fabrication of the lens can be made by a variety of techniques including lithography and laser beam machining.

The microscope body is held on a horizontal (cantilever) arm which can be positioned both vertically and laterally. Above this is the nanotip which is held on a vertical cantilever which allows it to be positioned accurately vertically and in the horizontal (x,y) plane. The nanoprobe is centred on the nanocolumn entrance aperture by a servomechanism which uses the current in a quadrant metal thin film which forms the first electrode in the nanocolumn. Below the microscope body is a sample stage on the end of a vertical cantilever. The electron beam is focussed onto the sample and can be moved across the sample by moving the end of the cantilever using standard nanopositioning techniques as used in STM, for example using piezo-electric mechanisms. If the backscattered electrons are detected using an electron detector (chaneltron) then an image of the atomic structure of the surface can be made. In the ultimate design the electron detector can be incorporated into the base of the microscope chip.

The design for a focussed ion beam system suitable for machining surface structures below 10nm in size can be adapted from the previous description by feeding liquid gallium to the nanotip and reversing the polarity of the voltages. In this arrangement the geometry is inverted so that the nanotip is positioned below the nanocolumn. (This is to prevent liquid gallium from contaminating the microscope.)

A practical system for a working microscope is shown in figures 1 and 2. This is for a version where the nanotip, electron detector and sample holder are separated from the microscope body. The incorporation of one or all of theses elements into a single 'microchip' is a further simplification of the design. In figure 1 is shown, on the left, the body of the microscope which consists of a nanocolumn or nanocolumns, 4 and 5, which produce a narrow (<50 nm) on-axis beam. The nanotip, 2, is at the end of a microstructure, 1, which is attached to the vertical cantilever (not shown) and positioned centrally and greater than 10nm from the first (entrance) aperture, 3, of the nanocolumn.

The nanocolumn can be in one or more parts as shown and defines an axial beam of lateral dimensions less than 50nm. A typical nanocolumn, 4, is shown on the right of the figure and is made of a thin multilayer film consisting of alternate metal (conducting) layers, 10, interspaced with insulating layers, 7, through which a circular aperture, 3, is made by lithography or using a focussed ion beam (FIB) 'milling machine'. The total length of the nanocolum(s) may be up to 2 μm and is sufficient to accurately determine the (on-axis) direction and phase space emittance of the electron or ion beam. The nanotip, 2, is positioned above the aperture as shown and voltages are applied to the tip and the nanocolumn electrodes as described in the previous application (GB 02213772.7). The beam defined by the nanocolumn has an axis, 9, which is concentric with the multi-element, microscale, einzel lens. This lens consists of metal (conducting) electrodes, 8, interspaced with insulators, 6. The assembly shown consists of 4 metal electrodes interspaced with insulators and is positioned at distances of only a few microns from the nanocolumn from which it is separated by an insulating or metal film with an aperture of the same dimension as the microlens. Suitable aperture diameters for this lens are given in the previous application. Increasing the number of metal conducting electrodes in the stack can reduce aberrations in this lens.

Fig. 2 shows one of the ways of constructing the microscope so that it is possible for the microlens to focus the beam at a point less than 50 μm from the end of the instrument. This condition is necessary if the beam is to have a lateral size less than 1nm and approaching 1 Å. (This beam spot essentially determines the resolution of the instrument.) The whole microscope is shown on the right and consists of the 'chip' or body, 1, rigidly attached to the horizontal cantilever arm, 13, which can be positioned using standard techniques of nanopositioning. A vertical cantilever above this holds the nanotip and this can be moved vertically and scanned in the horizontal plane. The sample is mounted on a special retainer, 7, which has a small surface area for attaching the sample. (This atomic resolution arrangement can only accommodate small area samples; for larger areas the focal length of the microlens is increased and the resolution degrade to around 1nm.) A further vertical cantilever, 10, below the microscope body holds the sample retainer and provides a means of positioning the sample at the correct vertical distance as well as scanning in the horizontal (x,y) plane.

The details of the microscope body or chip, 1, are shown on the left. A series of steps are produced by lithography, or micromachined with laser beams, in one edge of the chip. The bottom step is only a few μms thick and wider than about 20 μm. On this step, 6, are formed the multiplayer assembly, 4, which is essentially the body of the microscope as shown in the left hand side of fig. 1. The multilayer is grown by atomic deposition in two stages. First the layers corresponding to the electrostatic lens are produced and a hole, 3, corresponding to the lens aperture is fabricated in the layers by lithography near to the edge of the step corresponding to the letter A in the diagram. (Many holes can be produced in one lithographic procedure and each can be a separate microscope.) The top layer is covered with a nanometre thick film of gold or carbon and the successive multilayers are then grown (by atomic deposition) corresponding to the layers of the nanocolumn. The layers are produce using a horizontal mask which allows each separate layer to terminate at a different position along the step. This provides an essential method of attaching electrical contacts to the electrodes in the microscope, as illustrated by the exposed area, 5. Finally the nanocolumn hole is drilled through the top multilayer on axis with the electrostatic lens using a focussed ion beam. (This can also be made by state of the art e-beam lithography and dry etching techniques.)

In operation the nanotip, 2, is centred on the aperture and the voltages on the lens adjusted to focus the beam, with axis, 8, onto the sample at focal point, 9. The thickness of the support step, 6, and the focal length are arranged so that there is a sufficiently large enough gap for the backscattered electrons to be recorded with the channeltron, 11. The step structure of the edge is necessary to allow the body, or stem of the nanotip sufficient space so that the tip can be positioned over the microscope entrance aperture.

Two further adaptations are possible to allow the microscope to be contained in a single chip. Firstly the nanotip and a microscopic cantilever can be produced in the body of the chip. (This would probably be a horizontal cantilever.) Secondly the detector can be fabricated into the base of the chip. For this purpose it is probably better to use a semiconducting avalanche type detector for the electrons. It is even possible to consider incorporating the mechanisms to scan the sample within the base of the chip to make the ultimate SEM on a chip.

Claims

A sub-miniature scanning electron microscope which is made from a nanocolumn followed closely by a microcolumn. The nanocolumn, in its simplest form, contains apertures to reduce the beam dimensions but in its best arrangement consists of an accelerating column which collects the electrons from a nanotip and focuses them into a narrow almost parallel beam of diameter less than 50nm. The microcolumn is a multi-element lens which focuses the electrons at a point less than 50 microns from the end of lens. The overall layout of the instrument allows for the nanotip to be centred over the first aperture of the nanocolumn using a moveable cantilever. The beam spot is focussed onto a sample which is fixed to a vertical cantilever so that the sample can be scanned in the beam so to produce an image using the backscattered electrons. There are several obvious modifications of this design concept which include,

1) A variant where liquid gallium is fed to the nanotip to produce a focused positive ion beam. In this arrangement the voltages on the electrodes are reversed in polarity.
2) A variant where the nanotip is on a cantilever which is made integral with the microscope body or chip. The movement of the cantilever is effected by mechanisms (such as piezos) which are also integral to the chip.
3) A variant where the electron detector is made into the base of the chip instead of being a separate item.
4) A variant where the sample movement is effected by mechanisms integral to the chip.
5) A variant where electrostatic deflector electrodes are used to scan the electron beam over the sample.

The diameter and length of the nanocolumn are key elements to the final performance of the instrument and can cover a wide range of both internal diameters and lengths so that they define the direction and the lateral beam dimension. Similarly the method of construction may not be confined to using multilayers, particularly the einzel lens which may be constructed separately and positioned with internal or external cantilevers so that its axis is concentric with the nanocolumn.

ABSTRACT

Focussed Electron and Ion Beams-Part 2

A sub-miniature scanning electron microscope is constructed from a nanocolumn which collects, accelerates and focuses electrons from a nanotip and forms them into an almost parallel beam with nanometre lateral dimensions. These electrons are subsequently focussed to atomic dimensions using a multi-element microscopic einzel lens.

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